Atmospheric Environment 175 (2018) 33–43

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Review article

An overview of monitoring and reduction strategies for health and climate change related emissions in the Middle East and North Africa region

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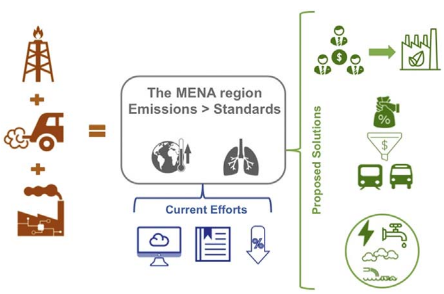
GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:
Health emissions
Climate emissions
Air quality
Transport and energy
Water-energy-pollution nexus
Legislations and control technologies

ABSTRACT

This review assesses the current state of air pollution in the Middle East and North Africa (MENA) region. Emission types and sources in the region are identified and quantified to understand the monitoring, legislative and reduction needs through a systematic review of available literature. It is found that both health (e.g., particulate matter, PM; and heavy metals) and climate change (e.g., carbon dioxide and methane) emissions are increasing with the time. Regarding health emissions, over 99% of the MENA population is exposed to PM levels that exceed the standards set by the World Health Organization (WHO). The dominant source of climate change emissions is the energy sector contributing ~38% of CO_2 emissions, followed by the transport sector at ~25%. Numerous studies have been carried out on air pollution in the region, however, there is a lack of comprehensive regional studies that would provide a holistic assessment. Most countries have air quality monitoring systems in place, however, the data is not effectively evaluated to devise pollution reduction strategies. Moreover, comprehensive emission inventories for the individual countries in the region are also lacking. The legislative and regulatory systems in MENA region follow the standards set by international environmental entities such as the WHO and the U.S. Environmental Protection Agency but their effective reinforcement remains a concern. It is concluded that the opportunities for emission reduction and control could be best implemented in the road transportation sector using innovative technologies. One of the potential ways forward is to channel finance flows from fossil fuel subsidies to upgrade road transport with public transportation systems such as buses and trains, as suggested by a 'high shift' scenario for MENA region. Furthermore, emission control programs and technologies are more effective when sponsored and implemented by the private sector; the success of Saudi Aramco in supporting national emission monitoring is one such example. Finally, an energy-pollution-water nexus is assessed for the region as an integrated approach to address its urban issues. The assessment of topic

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https://doi.org/10.1016/j.atmosenv.2017.11.061
Received 6 July 2017; Received in revised form 29 November 2017; Accepted 30 November 2017
Available online 05 December 2017

areas covered clearly suggests a need to control the main sources of air pollution to limit its relatively high impact on the human health in the MENA region.

1. Introduction

Air pollution has an adverse effect on human health (Heal et al., 2012) and contributes to climate change (Waked and Afif, 2012). On a global scale, developing countries are major contributors to air pollution due to their growing economies that result in the emergence of emissions-generating sectors including energy, transport and industrial (Galeotti and Lanza, 1999; Kumar et al., 2015, 2016). The Middle East and North Africa (MENA) region is one of the major contributors worldwide to global health and climate change emissions (El Fadel et al., 2013). Countries within the region include Algeria, Bahrain, Egypt, Jordan, Iran, Iraq, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, Kingdom of Saudi Arabia (KSA), Syria, Tunisia, Turkey, United Arab Emirates (UAE) and Yemen (El Fadel et al., 2013). The region hosts about 355 million people living in overpopulated cities that suffer from air pollution (El Fadel et al., 2013). Air pollution attributed to about 125,000 lives lost in MENA region in 2013, constituting 7% of total premature deaths (Saade, 2016). Such deaths also resulted in a loss of more than US$ 9 billion from annual labor income in 2013 and welfare losses amounting to 2.2% of regional GDP (Saade, 2016).

The ambient environment of the MENA region is injected with a large amount of dust caused by desert storms (Parajuli et al., 2016). Furthermore, high on-road emissions in the region are attributed to older on-road vehicles, inefficient fuel usage and unregulated control of exhaust emissions (Waked and Afif, 2012; Chapman, 2007). For example, particulate matter having 10 μm or smaller (PM_{10}) and sulphur dioxide (SO_2) concentrations continuously exceed the World Health Organization (WHO) standards in Egypt, Iran and UAE (Waked and Afif, 2012). The region is also amongst the highest global contributors of carbon monoxide (CO) and nitrogen oxides (NO_x) emissions in countries such as Iran, KSA, Iraq, Turkey and Egypt (Waked and Afif, 2012). Consequently, the highest numbers of deaths and economic costs are attributed to air pollution in Egypt and Iran (Saade, 2016).

The MENA region possesses 60% of the world's proven oil reserves and 45% of natural gas resources (El Fadel et al., 2013). Hence, fossil fuels are the main source of energy resulting in considerable climate change emissions. Oil producing countries such as Qatar, UAE and Kuwait rank among the top per capita emissions relative to per capita income (Baehr, 2009). Iran and KSA resulted in 65% of the region's fossil-fuel-related carbon dioxide (CO_2) in 2010 (Farzaneh et al., 2016).

The MENA region has the fastest growth rate in emissions globally and is responsible for 4.5% of global greenhouse gas (GHG) emissions contributing to climate change (El Fadel et al., 2013). The region is already vulnerable to climate change and suffers from fresh water scarcity and rapid population growth (Evans, 2009). Climate change models predict an overall temperature increase of ~1.4 K by mid-century and ~4 K by late-century (Evans, 2009). Such a change in conditions will result in a considerable decrease in precipitation in Turkey, Syria, Iraq and Iran (Evans, 2009). There will be an inevitable loss of viable rain-fed agricultural land and increases in the length of the dry season (Evans, 2009). In contrast, precipitation is expected to increase in the southernmost region by 25% in contrast to current precipitation rates by late century (Evans, 2009).

Governments in MENA region have started to commit to international agreements to mitigate and adapt to climate change by setting targets for renewable energy penetration (El Fadel et al., 2013). Other efforts to reduce emissions such as the use of natural gas for electricity production are being encouraged (Farzaneh et al., 2016).

A considerable number of studies have focused on the air pollution crisis in MENA, as summarised in Table 1. The majority of past studies have focused on identifying quantities and sources of major polluting sources with limited emphasis on addressing the issue. Generally, their focus has been on a particular city or a country to characterise the nature of its air pollutants and their adverse impacts. Table 1 also indicates that studies were mostly carried out in Lebanon and Egypt as opposed to other countries. Existing studies create a good basis for identifying the problem on a national level, however, regional studies that explore efforts to address the issue are limited. Furthermore, governments have put systems and standards in place. However, the extent to which these measures are effective has not been investigated thoroughly.

For the first time, this review article attempts to capture a comprehensive overview of the studies conducted on the main types and sources of air pollution in the MENA region, the monitoring systems put in place to quantify the issue, the national and regional legislations

Table 1
Overview of emission studies in the MENA region.

Location	Study Focus	Major Findings	Author (year)
Kuwait	Source apportionment of airborne nanoparticles	Six sources identified were fresh traffic emissions (46%), aged traffic (27%), industrial (9%), regional background (9%), sources (6%) and dust (3%).	Al-Dabbous and Kumar (2015)
Cairo, Egypt	Integration of GPS and GIS to Study Traffic Congestion	A positive correlation was found between travel time and emissions quantity for gasoline vehicles and no correlation for diesel vehicles.	El-Mansy (2013)
Lebanon	Emissions inventory from road transport	Highest contributors to CO and NO_x are countries that exceed 20 million inhabitants.	Waked and Afif (2012)
Beirut, Lebanon	Origin and variability of PM_{10} and $PM_{2.5}$	Higher percentages of sulfates and nitrates were in fine PMs from vehicle emissions and construction debris.	Saliba et al. (2010)
Ankara, Turkey	Air pollution forecasting using air pollution index	Air quality in Ankara was more affected by meteorology rather than emissions.	Genc et al. (2010)
Cairo, Egypt	PAHs in road dust	The carcinogenic content of PAHs is 0.8–46.6%; PAHs are greater near traffic routes and industries.	Hassanien and Abdel-Latif (2008)
Beiruit, Lebanon	Effect of transport emissions on $PM_{10–2.5}$ and $PM_{2.5}$ composition	Cu and Zn were generated from worn brakes and tires in high traffic areas	Saliba et al. (2007)
Lebanon	Field study of CO, SO_2, PM_{10} and O_3	Vehicle-induced emissions contribute to CO levels while winter heaters cause SO_2; High levels of PM_{10} and O_3 result from transport.	Saliba et al. (2006)
Beirut, Lebanon	Seasonal behaviors of lower carbonyl compounds	Vehicle emissions are the dominant source of carbonyls	Moussa et al. (2006)
Beirut, Lebanon	Measurements and composition of $PM_{10-2.5}$	Inorganic ions and organic species found in higher concentrations of $PM_{2.5}$; In $PM_{10-2.5,}$ higher water concentrations were observed.	Shaka and Saliba (2004)

enacted to control emissions and the emission control technologies being implemented on the ground. Finally, the most feasible solutions for emission reduction are proposed and the notion of an integrated energy-pollution-water nexus is assessed for the MENA region.

2. Scope and outline

Given the direct consequences and risks caused by air pollution in MENA, the focus of this study is to comprehensively review published literature on the monitoring of health and climate change emissions and reduction strategies in the region. Firstly, the types of emission sources are discussed in Sections 3 and 4, followed by a survey of the studies on emissions in the MENA countries (Section 5). It is imperative that emissions are identified, quantified and monitored in order to reduce their negative impact (Waked and Afif, 2012). Hence, monitoring strategies adopted in MENA are discussed in Section 6. Moving on, legislation and mitigation strategies set to control emissions as well as the adopted control technologies in the region are illustrated in Sections 7 and 8. Further, the concept of energy-pollution-water nexus is evaluated for the region (Section 9). The final section concludes the study topics along with highlighting the research gaps and needs.

3. Types of emissions

Air pollutants could broadly be divided into four broad categories: (i) gaseous pollutants including SO_2, NO_x, CO, ozone (O_3) and volatile organic compounds (VOCs); (ii) persistent organic pollutants such as dioxins; (iii) heavy metals; and (iv) particulate matter (PM) such as PM_{10}, $PM_{2.5}$ and PM_1 (Kampa and Castanas, 2008; Heal et al., 2012). Furthermore, these emissions could be broadly categorised as health-related and climate-related emissions as described in Sections 3.1 and 3.2, respectively.

3.1. Health-related emissions

Gaseous pollutants and PM have acute and chronic effects on human health and are usually considered as health-related emissions (Kampa and Castanas, 2008). Numerous studies have linked atmospheric pollutants to health problems that appear when pollutant levels exceed standards set by agencies such as the United States Environmental Protection Agency (US EPA) and WHO (Curtis et al., 2006). Air pollution exposure has resulted in around 7 million premature deaths which amount to one in eight of total global deaths as reported by the WHO (Jasarevic et al., 2014). Traffic-related air pollution is considered as a dominating contributor (Han and Naeher, 2006).

The MENA region is not an exception to the health threats posed by air pollution. Despite the evident health concerns associated with air pollution in MENA region, the studies focusing on exposure to emissions have received little attention due to the lack of consistent environmental data. Table 2 summarises the available studies carried out on the effect of PM levels and heavy metals on health in major cities in Egypt, Lebanon and Iran. Monitoring studies indicate that dust storms and urban population growth are the key reasons for PM concentrations exceeding WHO standards (Tsiouri et al., 2015). A recent study by Naimabadi et al. (2016) suggested dust storms in Iran as the main contributor to cytotoxicity. The World Bank reports that over 99% of the MENA region's population is exposed to $PM_{2.5}$ levels that exceed the WHO guideline (The World Bank, 2016). Fig. 1 shows the regional mean annual exposure to $PM_{2.5}$ showing evidence that MENA experiences significant PM pollution over the course of the past three decades compromising human health and productivity. Population-weighted exposure to ambient $PM_{2.5}$ pollution is defined as the average level of exposure of a nation's population to the pollutant's concentrations (The World Bank, 2016). Fig. 1 shows that the mean annual exposure to $PM_{2.5}$ in the MENA region has been increasing at a slow rate, however, it has been more than double the air quality standard set by the European Commission at 25 μgm^{-3} with no evidence of reduction (European Commission, 2016; The World Bank, 2016).

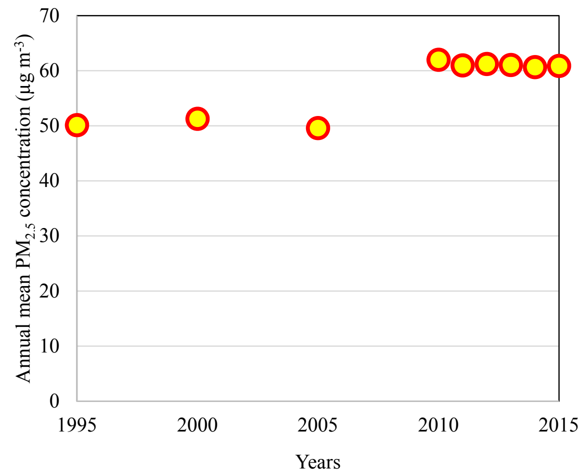

Fig. 1. Annual mean $PM_{2.5}$ exposure (µg m^{-3}) based on the MENA region (The World Bank, 2016).

Epidemiological and toxicological studies performed for the MENA region have shown that high PM levels cause respiratory and cardiovascular diseases (Tsiouri et al., 2015). Furthermore, Chaaban et al. (2001) showed a direct correlation between increasing mortality rates and air pollution exposure in Lebanon. Air polluting activities such as traffic, industries, burning of waste and oil production are prevalent in MENA and hence the health of its nations is compromised and negatively reflects on its economies.

3.2. Climate-related emissions

MENA is one of the most vulnerable areas to the risks of climate change where there is a predicted drop in average precipitation levels by 20–30%, temperatures will increase by some 2 °C, and in the Nile

Table 2
Overview of health emission studies in the MENA region.

Location	Study Focus	Major Findings	Author (year)
Ahvaz, Iran	Effect of PM_{10} on the human lung	Cytotoxicity and the risk of PM_{10} to human lung may be more severe during dust storm than normal days	Naimabadi et al. (2016)
Middle East Area	A review of the concentrations, sources and exposure risks associated with PM	The levels of both PM_{10} and $PM_{2.5}$ exceed the WHO guidelines; The effects of PM include respiratory and cardiovascular diseases	Tsiouri et al. (2015)
Cairo, Egypt	A lead emission inventory	Sources of lead include smelters, Mazout combustion, battery factories, copper foundries and cement factories.	Safar et al. (2014)
Cairo, Egypt	Exposure of pediatric groups to cadmium	Efforts for the disposal of Cd wastes and prevention of smoking in public places are recommended.	Hossny et al. (2001)
Lebanon	The economic effects of pollution from mobile sources on health	Highlighting the mitigation options applicable for the country and for similar developing nations	Chaaban et al. (2001)

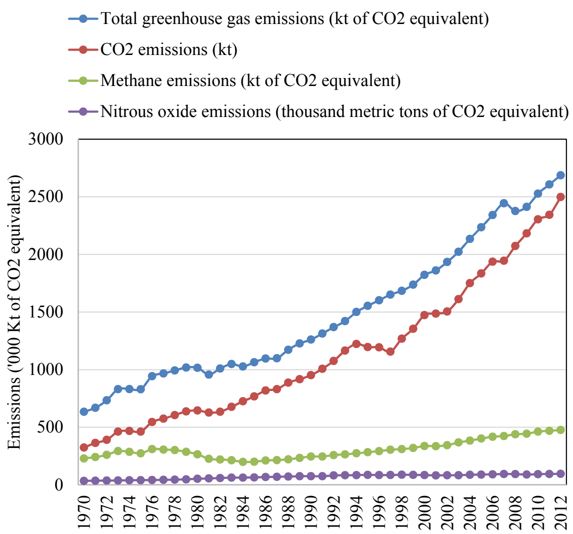

Fig. 2. Breakdown of GHG Emissions in tonnes of CO_2 equivalent regional aggregate figures for the MENA over a thirty year period (The World Bank, 2016).

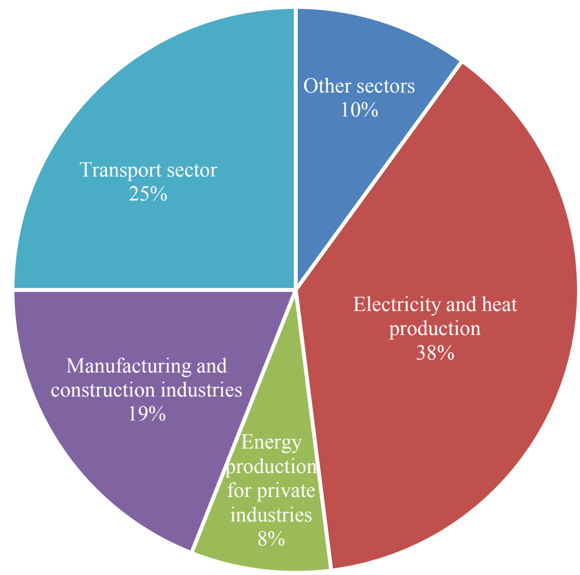

Fig. 3. Percentage contribution of each polluting sector to CO_2 emissions in MENA region in 2014 (International Energy Agency, 2016).

Delta a sea level rise of 0.5 m will displace two million people leading to more than $35 billion in loss of land, property, and infrastructure (Cervigni et al., 2009). Emissions that result in climate change are known as GHG emissions and include CO_2, methane (CH_4), nitrous oxide (N_2O) and CFCs (Curtis et al., 2006; Kumar and Imam, 2013). Carbon emission levels are predicted to cause an increase in global temperatures of between 1.4 and 5.8 °C (Chapman, 2007). MENA is experiencing rising emissions as reported by the World Bank (The World Bank, 2016). Fig. 2 clearly shows that climate change emissions in MENA increased by almost five times its quantity over the past three decades, which is bound to contribute to the global climate issue. In KSA, Bahrain, Kuwait, and the UAE; CO_2 emissions increased on average 6% annually between 2005 and 2014 in parallel with increases in GDP and energy consumption while NO_2 increased about 5% per year (Lelieveld et al., 2015). Starting the year 2005, the GDP in Iraq has been increasing at a rate of 6–7% per year, accompanied by an increase in energy consumption and CO_2 emissions of 4–5% per year (Lelieveld et al., 2015).

The increasing demand for water and electricity coupled with the rising industrial sector contribute to increased CO_2 emissions and intensify the effects of climate change (Sengul et al., 2009). The region has high population centers located in coastal areas. Hence, any changes in climate that result in a rise in sea level are expected to have significant effects (Sengul et al., 2009). This shows that the increase of GHG emissions in MENA has serious implications for the livelihoods of its inhabitants. Due to international pressures and agreements, scholars have focused on climate change, as listed in Table 3. Studies focused on climate change emissions, their impacts, sources and abatement techniques.

4. Emission sources in MENA

MENA is host to rapidly growing urban populations and industrial sites (Waked and Afif, 2012). Road transport, desalination, energy and cement production are some of the dominant sources of air pollution. Fig. 3 shows the quantities of CO_2 emissions produced by different sectors in MENA. It is imperative to identify sources of air pollution to assess the efforts and resources dedicated to tackling these issues. In the case of MENA, energy (Section 4.1) and transport (Section 4.2) sectors are the highest contributors to CO_2 emissions, followed by the industrial sector (Section 4.3).

4.1. Energy production sector

Fig. 3 indicates that carbon emissions from energy production

Table 3
Overview of climate change emission studies in the MENA region.

Location	Study Focus	Major Findings	Author (year)
Middle East	Changes in atmospheric NO_2	Upward NO_2 trends have been observed over major MENA cities due to low air quality control, economic crisis and armed conflict.	Lelieveld et al. (2015)
Cairo, Egypt	The impact of city growth on emissions	Impact analysis estimated traffic volumes added to the congested metro corridors.	Huzayyin and Salem (2013)
MENA	Renewable energy market penetration	Reductions in GHG of 6–38% achieved depending on target penetration and promising up to 54% savings on investment.	El Fadel et al. (2013)
Lebanon	Emission inventory	93% of CO emissions, 67% of NMVOC and 52% of NO_x originate from on-road transport while 73% of SO_2, 62% of PM_{10} and 59% of $PM_{2.5}$ from power plants and industrial sources.	Waked et al. (2012)
MENA	Energy consumption, economic growth and CO_2	Not all MENA countries need to sacrifice economic growth to decrease their emission levels as they may achieve CO_2 emissions reduction via energy conservation.	Arouri et al. (2012)
Middle East	Factors affecting CO_2 emission	Total primary energy consumption, foreign direct investment, GDP and total trade increase CO_2 emission.	Al-Mulali (2012)
Middle East	Future predictions produced by 18 global climate models	The models predict an overall temperature increase. The largest change, however, is a decrease in precipitation that occurs in an area covering the Eastern Mediterranean.	Evans (2009)
Middle East	Effect of CO_2 to environmental stress	The industrial sector, desalination and power plants are linked to fossil fuel combustion	Sengul et al. (2009)
Cairo, Egypt	Origin of black cloud	Traffic is the major source of black cloud during daytime and even in autumn when biomass burning takes place.	Mahmoud et al. (2008)

(electricity and heat production) rank as the highest among all other air polluting sectors (El Khoury, 2012). Empirical literature exhibits a relationship between per capita income and environmental pollution known as the Environmental Kuznets Curve, EKC (Alkhathlan and Javid, 2013). In the MENA region, there is a positive relationship between emission production and the increased income where a rising economy causes an increase in pollution (Arouri et al., 2012). Carbon emissions from energy production are not equal across the whole region. For example, KSA, Egypt, UAE, Kuwait, and Iraq are the top five emitters, contributing up to 70% of total carbon emissions from the energy sector (El Khoury, 2012). The carbon emission share of KSA to the worldwide emissions was 1.54% in 2008 (Alkhathlan and Javid, 2013).

The sole reliance of the region on non-renewable resources of energy calls for regulatory bodies to shift focus away from fossil fuels to address air pollution. Moreover, the energy efficiency adaptation measures in MENA countries are still limited. Only Sudan, Bahrain and Oman are considered to be practicing energy efficiency techniques within their infrastructure while KSA and Egypt are the least efficient (Ramanathan, 2005). Electricity is subsidised in most countries resulting in a considerably low cost per kilowatt-hour hence consumers are not encouraged to conserve energy (El Khoury, 2012). To reduce emissions from this sector, tariffs have to be phased out over a period of time that may cause social repercussions. Moreover, the evident inefficiency in behaviors and in power infrastructure must be addressed through awareness programs and national investments for system upgrades.

It is evident that the energy sector in MENA is the main air pollution contributor. However, there is limited opportunity to mitigate its emissions since energy is imperative for economic development, which is the main priority for the region.

4.2. Road transportation

The road transport sector accounts for 26% of global CO_2 emissions (Chapman, 2007). As is the case worldwide, Fig. 3 shows that road vehicles are the second main contributor to pollutant emissions in MENA (El Khoury, 2012; Waked and Afif, 2012). MENA has the highest global GHG transport emissions per unit GDP at 150 tons CO_2 per $1 million of GDP (Yamouri, 2010). The fleet is dominated (~60%) by passenger cars where the low utilisation of public transport contributes to traffic congestion (Waked and Afif, 2012). Road vehicles cause the production of 59% of NO_x in most MENA countries (Waked and Afif, 2012). The sector is also responsible for 90% of CO emissions and 75% NMVOC (non-methane volatile organic compounds) in the region (Waked and Afif, 2012). Studies in Table 1 attribute PM emissions within cities to the transport sector, meaning that it should also be approached to make a difference to the PM emission problem. Since cities in MENA region are typically overpopulated with high traffic intensities resulting in notable emission rates, there is relatively a higher opportunity to address the issue of climate-related emissions through managing the road transport issue as opposed to the energy sector.

4.3. Industrial sector

The number of industries in MENA countries is increasing with time. For example, energy-intensive industries in Egypt are encouraged by low electricity tariffs, resulting in increased national consumption (El Khoury, 2012). Moreover, the availability of energy in the Gulf at subsidised rates attracts investors to establish energy-intensive industries such as steel, aluminum and fertilizers (El Khoury, 2012). Furthermore, hot-arid conditions have also contributed to higher domestic electricity consumption for cooling; for example, the cooling of buildings in KSA accounts due to 70% of electricity consumption (El Khoury, 2012). Energy-intensive water desalination also results in higher emissions (El Khoury, 2012). Finally, the oil and gas industry in the region is associated with an estimate of 50 billion m^3 of flared gas annually that makes it the second largest flaring region in the world (World Bank Group, 2008). The industrial sector is another area of plausible improvement where governments are called upon to set strict environmental legislation for industries and also to encourage industry investment in green projects that limit emissions and preserve natural resources.

5. National air quality monitoring strategies

Monitoring air quality and emissions is imperative to assess human exposure to pollution risks and assist authorities in formulating improvement plans (Waked and Afif, 2012; Tsiouri et al., 2015). The long-term changes in air quality are less studied in MENA than other regions (Barkley et al., 2017). In the Middle East, air pollution monitoring information is unavailable for about 28% of countries while in Africa it is unavailable for 66% of countries (Fajersztajn et al., 2014). This clearly demonstrates the need to improve air quality monitoring programs through analysis tools and decision support systems in the region as a whole (Abou Elseoud, 2005).

The remote sensing satellite technology is currently popular for large-scale air quality monitoring however it is not in use in MENA countries (El Raey, 2006). MENA countries resort to ground-based monitoring for regulatory compliance purposes, however, the installed systems are outdated in most cases (El Raey, 2006). Table 4 details information on the monitoring efforts carried out in the region showing that the largest North African and Gulf countries have had monitoring

Table 4
Existing monitoring systems in some MENA countries.

Country	Monitoring Efforts	References
Bahrain	Continuous monitoring was set up at four geographical locations in 1993 to monitor major air pollutants	Chaaban (2008)
Egypt	• Air quality monitoring network of 87 stations was implemented in 1998 • 128 chimneys monitor the emissions from the cement, fertilizer and petrochemicals sectors • Data collected from monitoring stations feeds into databases for decision support and data dissemination systems	EEAA (2010) Kamal (2015)
KSA	MEPA has collaborated with Saudi Aramco to conduct an air quality-monitoring program to operate ten monitoring and fifteen meteorology stations.	Chaaban (2008)
Morocco	Air quality measurements and vehicle emission monitoring in major urban cities employing sampling aerosols and gases, ambulant laboratories and analytical techniques for heavy metals	Abou Elseoud (2005)
Qatar	The government deployed a network of fixed and mobile air quality monitoring stations in industrial cities	Madan (2016)
Tunisia	• A national control and monitoring program is conducted • The national monitoring network is made up of twenty-five fixed and mobile stations to collect data for the annual state of the environment report	Chaaban (2008)
UAE	• The government deployed 15 fixed and 2 mobile stations in 2003 • Data is uploaded to a public website for people with respiratory problems • There are 46 air quality monitoring stations near cement factories	Chaaban (2008) Madan (2016)

systems in place for over a decade or two.

5.1. National emission inventories

Although a considerable number of countries have installed monitoring networks (Table 4), local inventory data are sparse resulting in higher uncertainty in modeling (Waked and Afif, 2012). As highlighted in Table 2, an inventory was developed in 1998 for Cairo to investigate the health risks of lead emissions (Safar et al., 2014). The study concluded that lead (Pb) is one of Cairo's major health hazards and was hence used to develop effective regulatory and control strategies (Safar et al., 2014). As a result, a decrease of more than 90% in lead emissions was attained in 2007 (Safar et al., 2014). Table 1 indicates another emission inventory developed for Lebanon to provide quantitative information for air pollution studies and input to air quality models (Waked et al., 2012). The spatial allocation of emissions shows that most emissions in Beirut result from on-road transport (Waked et al., 2012). The above-discussed inventories are an example of employing collected monitoring data to address emission mitigation through practicable national strategies. Similar inventories should be carried out in other countries and in the region on a regular basis to build a consistent database of emission sources to in turn control pollution.

5.2. Air quality and emissions monitoring in MENA

Tsiouri et al. (2015) reviewed the different PM sampling campaigns across MENA region. Lebanon suffers from heavy road traffic that results in considerable health emissions attracting the interest of scholars and authorities to conduct PM field campaigns (Tsiouri et al., 2015). PM_{10} and $PM_{2.5}$ sampling also took place in three different cities in Kuwait where particle mass concentrations were determined (Al-Dabbous and Kumar 2015). Likewise, total suspended particulate matter (TSP) samples were collected between 2010 and 2011 in Ahvaz, a city subjected to major dust storms (Sowlat et al., 2012). The broadest study carried out in the region focused on the chemical and physical properties of PM over one year (2006–2007) in Qatar, UAE, Iraq and Kuwait under the Enhanced Particulate Matter Surveillance Program (NRC, 2010). A common observation is that PM concentrations deduced from these studies exceed WHO and USEPA standards (Tsiouri et al., 2015). Data collected for these studies was not sufficient to perform health-effects research as more data is needed to provide statistical power and feed into strategic decisions (Tsiouri et al., 2015). However, the sampling campaigns provide an understanding of the com + position of pollutants.

A source attribution study was performed to assess the contributions of specific pollutants to the PM levels in Cairo using the CMB receptor model at six sampling stations (Abu-Allaban et al., 2007). Major contributors to PM_{10} included geological material, mobile source emissions, and open burning while $PM_{2.5}$ was caused by mobile source emissions and open burning (Abu-Allaban et al., 2007).

Moreover, a study of air quality data in Oman and Kuwait was carried out to monitor certain pollutants including methane, carbon monoxide, nitrogen oxides and dust (Abdul-Wahab, 2009). In Kuwait, a mobile laboratory that was equipped with sampling inlets was used while in Oman, air quality data was collected using a fixed station located at an LNG plant (Abdul-Wahab, 2009). Results showed higher levels of pollution in the urban residential area of Kuwait than in a suburban industrial area in Oman (Abdul-Wahab, 2009). Another comprehensive study employed ozone monitoring instruments to monitor NO_2, formaldehyde, SO_2 and glyoxal at one thousand locations over the Middle East for 2005–2014 (Barkley et al., 2017). Apart from NO_2, which is highest in urban locations, the levels of these trace gases were highest over oil ports and refineries in oil-producing countries like Bahrain, Kuwait, Qatar and UAE (Barkley et al., 2017).

It can be concluded that despite the considerable monitoring efforts in MENA, studies are inconsistent and make it hard to draw conclusive trends of various pollutants. Furthermore, studies are mostly performed in the Gulf or in larger countries such as Egypt for limited periods of time while the other MENA countries offer opportunities for pollution monitoring. There is a need for long-term and continous data collection over the whole region.

6. Institutional law and regulatory (ILR)

6.1. Regional, institutional and legislative efforts

To address the issue of air pollution, national regulatory authorities are looked upon to enact ILR systems to control emissions in MENA. The legislative systems and standards should be dictated by the data collected through continuous monitoring stations. However, as concluded in Section 6, most MENA countries lack reliable and long-term ambient air monitoring data that is collected intermittently and remain unutilised for analysis, interpretation and control (El Raey, 2006). Nevertheless, most Arab states have passed legislation to protect the environment in conformity with international regulations of WHO and US EPA (El Raey, 2006). Yet, more than half of MENA countries do not meet WHO guidelines (UNEP, 2014). This indicates a need to advance capabilities for ensuring the compliance with the set standards (El Raey, 2006).

Some of the MENA countries have developed air pollution prevention programs (UNEP, 2014). Since energy production is the main sources of air pollution, Algeria, Jordon and Syria offer incentives to increase investment in energy efficiency, clean technology and renewable energy (UNEP, 2014). In addition, Morocco has introduced a legal and regulatory framework for the energy sector; Jordan implemented a National Energy Efficiency Strategy for 2005–2020, which includes a renewable energy target of 10% by 2020 (UNEP, 2014). However, while a number of countries have set targets to achieve renewable penetration within their national energy mix, only Jordan is reported to have tax incentives to spur investment in renewable energy (UNEP, 2014).

Most MENA countries have set legislative systems and abatement programs to control air pollution emissions (Table 5). Despite existing emission control efforts, it is evident that most countries are in need of an effective environmental law enforcement system.

6.2. Transport emissions control

As discussed in Section 4, land transport contributes 25% of MENA air pollution. The initiatives directed at making public transport more attractive and fuel taxes directed at car use are ideal for reducing CO_2 emissions (Hensher, 2008). Policy tools considered in MENA include road pricing, increasing efficiency of existing systems and expanding public transit (El Raey, 2006). In Egypt, for example, there are legislations enforcing imported vehicles to be equipped with a catalytic converter (UNEP, 2008). In Kuwait and Lebanon, cars older than three years old require an annual roadworthiness test while Oman, Qatar, UAE and KSA carry out the test as part of their periodic inspections (UNEP, 2008). Likewise, Morocco, Syria and Tunisia established air quality programs to check vehicle emissions (UNEP, 2008).

Gettani et al. (2015) discussed a 'high-shift' scenario where investiment in urban passenger transportation showed a shift towards urban mass transportation in MENA region, transporting larger numbers of passengers reducing emissions per capita (Gettani et al., 2015). The study pointed out that revenue created from eliminating fuel subsidies in each country would significantly cover the increased transit investment costs needed for their studied scenario since the region spends 40 billion dollars annually on such subsidies (Gettani et al., 2015). However, the MENA region is already better equipped for automobile transport and most countries are among the largest producers of petroleum globally and hence provides fuel subsidies (Gettani et al., 2015). Consequently, in countries such as Egypt and Kuwait, the public

Table 5
An overview of emission reduction institutional, legal and regulatory systems in some MENA countries.

Country	Legislative Systems and Programs	References
Bahrain	A program was introduced in 1994 called "Fume watch" where civilians can report vehicles that were emitting smoke	El Raey (2006)
Egypt	• The government endorsed compressed natural gas (CNG) as it contains about 85% fewer pollutants than gasoline.	El Raey (2006)
	• The cement industry is subject to emission regulations set by Law 4 of 1994	Kamal (2015)
	• Egypt started implementing the strategy to address the open burning of waste.	UNEP (2014)
Jordan	• Law No. 1 of 2003 and "The Air Protection Regulation" (2000) both determine maximum allowable emission concentrations	Chaaban (2008)
KSA	• Concerned with establishing air quality standards for limits on SO2, PM, NOx, CO and H_2S.	Chaaban (2008)
Lebanon	• Law 341/2001 for reducing transport air pollution.	Chaaban (2008)
	• A national strategy has targeted a complete lead phase-out in gasoline.	
Morocco	• Law on waste management and disposal governs open burning of waste.	UNEP (2014)
Oman	• Designated a legal framework banning the burning of waste.	UNEP (2014)
Qatar	• Law Number 30 of 2002 details the standards for gas emissions	Chaaban (2008)
	• Industrial plants are subject to a quarterly inspection	
Syria	• Implemented a national action plan for controlling air emissions.	Chaaban (2008)

bus service is subject to the lack of funding, resulting in aging bus fleets and declining service frequencies (Gettani et al., 2015). The flexibility provided by private motorised vehicles is difficult to compete with when offering mass transport as an alternative (Gettani et al., 2015). Hence, there is a call for stricter legislation and policy reforms in the region to direct finance flows from fuel subsidies to enhancing public transportation and, in turn, mitigating air pollution.

7. Control measures in MENA countries

7.1. Control technologies in energy sector

Technologies that control emissions produced by the power sector include electric interconnection, deployment of combined cycles, using natural gas, renewable energy, reduction of transmission losses and demand-side management (Chaaban, 2008). Gulf countries (GC) have witnessed the conversion of the use of fossil fuels in power plants to the use of natural gas thereby reducing ambient SO_2 (Chaaban, 2008). In Syria, there was a shift towards natural gas as the main fuel for the power sector (Chaaban, 2008).

Renewable energy is climbing the public agenda in many countries for reasons of energy security, independence and local value creation (Hanger et al., 2016). The MENA countries possess some of the best production conditions for solar power (Cervigni et al., 2009; Haller et al., 2012). At present, three out of eighteen countries in the region have between 11% and 30% of their electricity mix coming from renewable energy sources, while the rest have less than 10% (UNEP, 2014). The ambitious Moroccan solar plan set a Concentrated Solar Power (CSP) flagship project for the entire region (Hanger et al., 2016). International players such as the African Development Bank, the World Bank, and the European Investment Bank are supporting the Moroccan government through loans and grants (Hanger et al., 2016). There is also an opportunity for CSP to replace existing diesel generators to satisfy local needs and to export to Europe through Spain (Hanger et al., 2016). Another technology adopted to reduce emissions resulting from power production was applied in Tehran where recovering exhaust hot gases of an existing gas turbine power plant is used to meet dynamic thermal energy requirements of a residential area and feed a steam turbine cycle (Tehrani et al., 2013).

Despite technologies set to reduce emissions in the energy sector, Farhani and Shahbaz (2014) suggest that future reductions in CO_2 emissions might be achieved at the cost of economic growth. Most MENA countries are developing countries that dedicate their resources to growth and would hence consume more electricity resulting in an increase in emissions at first, followed by a decrease after a certain average GDP is attained. Hence, pursuing emission mitigation opportunities within power production will not be the preferred route.

7.2. Emission control measures in transportation sector

The control measures for transport emissions include promoting mass transport, improving vehicle fleet status, alternative fuels, traffic management and urban planning (Chaaban, 2008). Some governments in the MENA have begun to feel the burden of not taking immediate action where in Egypt, a new traffic law requires vehicle emissions to be periodically checked (El Raey, 2006). Furthermore, as detailed in Table 5, the introduction of CNG buses, taxis and passenger vehicles in GC led to 9% fewer release of PM (Chemonics International, 2004; El Raey, 2006; Chaaban, 2008). As a result of such efforts, pollution from diesel buses dropped an average of 50% and an annual $650,000 in fuel cost savings (Chemonics International, 2004). The UAE set a ban on leaded fuel resulting in its complete phase-out to introduce natural gas as a substitute (Chaaban, 2008). Furthermore, it aims to have 20% of government-owned vehicles and taxis to run on CNG and Ultra Low Sulphur Fuel (ULSF) (Chaaban, 2008). Similarly, service stations in KSA sell lead-free gasoline (Chaaban, 2008). Qatar and Yemen also made the shift towards unleaded gasoline (Chaaban, 2008). Lebanon, for example, has targeted a complete lead phase-out of gasoline and the reduction of diesel sulphur content (Chaaban, 2008). Tehran implemented an emissions reduction project achieving for every $1 million investment a reduction in air pollution of 1235 tons for new vehicles, 391 tons for old vehicles, 186 tons for public transportation (Tharakan, 2001).

Despite the efforts, the region is generally characterised by obsolete vehicle types with low efficiency and poor emission controls, the high average age of vehicle fleets and the lack of strong emission inspection programs (Tharakan, 2001). The increasing rate of emissions indicates the ineffectiveness of such control measures on a regional level since the above-mentioned programs are short-lived and specific to certain locations. There is a need for more comprehensive and consistent emission control programs in MENA.

7.3. Control technologies in industrial sector

Air emission control equipment are becoming common in new or upgraded industrial facilities in MENA region (El Raey, 2006). Technologies that control emissions resulting from the industrial sector include switching to natural gas, boiler improvement, energy efficiency, cogeneration and efficient motors (Chaaban, 2008). The oil and gas sector in the Gulf is taking the lead in the development of low-carbon technologies, including renewable sources of energy and carbon capture and storage (CCS) (Cervigni et al., 2009). CCS means capturing CO_2 from large emission sources to store it in safe geological structures (Algharaib and Al-Soof, 2010). The captured CO_2 can be used in Enhanced Oil Recovery (EOR) methods where CO_2 is preferred as an injected gas (Algharaib and Al-Soof, 2010). Other actions to reduce emissions in this sector include the elimination of flaring (El Raey,

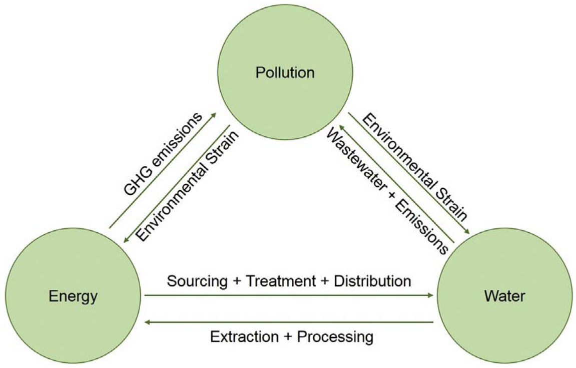

Fig. 4. Illustration of a simplified energy-pollution-water nexus concept, showing interlinkages between various environmental factors and processes.

2006).

Other industrial activities in the region that contribute to air pollution include petrochemical complexes, fertilizer plants, refineries, cement factories and iron and aluminum smelters (El Raey, 2006). The industrial sector is considered a major polluter in most countries with minimal efforts addressing the issue. In Syria, for example, craft industries such as tanneries and textile use highly polluting technologies (El Raey, 2006). Similarly, in Cairo, clouds of black smoke result from pottery and metals industries and the burning of rice straw (El Raey, 2006). The lead smelting industry is located in highly populated areas in Cairo (El Raey, 2006). Consequently, the USAID has been working on moving lead smelters out of downtown Cairo as part of the initiative discussed in Section 6.2 (Chemonics International, 2004; El Raey, 2006). The program caused lead emissions to fall by 65% translating into 500 fewer cancer cases, 4 500 fewer premature deaths and more than $30 million saved in health costs (Chemonics International, 2004). It is evident that programs and efforts by the private sector in the MENA region are effective in reducing emissions hence countries should encourage and facilitate such initiatives.

8. Urban nexus

8.1. Concept and benefits for MENA cities

The term nexus is commonly used to portray interactions between water, food, climate and energy (Chirisa and Bandauko, 2015). Each aspect within the nexus either contributes to the production of another or impacts its existence. In the 2013 UN General Assembly, it was pointed out that attention needs to be given to the inter-linkages between water and energy sectors in framing the post-2015 development agenda (Kumar and Saroj, 2014). Kumar and Saroj (2014) argue that there is a need for establishing a broader nexus to include water, energy and pollution where implications of energy production, water consumption and environmental pollution are captured. Such a nexus is imperative because these aspects are typically managed in isolation rather than as an integrated system, resulting in poor management (Kumar and Saroj, 2014; Chirisa and Bandauko, 2015). An integrated framework will support decision-makers in better understanding risks, to put in place effective monitoring, legislative and control systems (Chirisa and Bandauko, 2015).

This section focuses on the interrelation between energy, water and pollution. Fig. 4 depicts the inter-linkages between the three proposed aspects where water is needed in the production of energy and energy is needed for the extraction and treatment of water (Chirisa and Bandauko, 2015). Producing energy and managing water result in the pollution of the environment; both air and water. On the other hand, air and water pollution put strain and intensify the challenges of meeting water and energy needs (Chirisa and Bandauko, 2015). To further illustrate the nexus depicted in Fig. 4, activities that embody the interrelation between the three pillars of the nexus are listed in Table 6.

Table 6
Description of urban nexus parameters and relationships.

Energy-Pollution	
The energy sector causes pollution through: ● Hydrocarbon production results in water pollution ● The combustion of carbon-based fuels causes climate change and health emissions Pollution affects energy as follows: ● Polluted water is not fit for fossil fuel extraction ● Polluted air and emissions put a strain on renewable energy resources (e.g., solar and wind)	Kumar and Saroj (2014)
Energy-Water	
How energy is needed in the water sector for: ● Construction in the water sector including wells, conveyance pipes, treatment plants and manufacturing of equipment ● Operational processes include abstraction and conveyance through wells, pumps and pipes ● End water use like heating and cooling ● The treatment of wastewater demands energy, to be reused or discharged back into nature	Rothausen and Conway (2011) Kumar and Saroj (2014)
About 15% of the world's water is used to produce energy through the following activities: ● Water is used in supply chain of energy: extraction, transport and processing ● Small amounts of water are needed for maintenance, operation and transport ● The electricity sector requires water for the cooling systems of thermal power plants ● Renewables such as bio-ethanol require water for extraction and cooling	Damerau et al. (2015) Wakeel et al. (2016)
Pollution-Water	
Pollution affects the water sector: ● Polluted water impacts and depletes the viable water resource. The water sector causes pollution: ● The water industry results in water pollution during its treatment process. ● Water extraction, treatment and transport employ energy resources and road transport that result in air pollution.	Ely (2017)

A holistic assessment proved imperative from the perspective of urban management (Kumar and Saroj, 2014). For example, energy causes both air and water pollution during its production and consumption hence an integrated nexus would help in understanding dynamic interrelations and quantitative indicators for water and air pollution produced per unit of energy produced (Kumar and Saroj, 2014). Furthermore, there is a new paradigm called Cities of the Future (COF) where the emergence of megacities under a scenario of limited resources is proposed (Novotny, 2013). COF suggests retrofitting the city to embrace key issues such as energy and water (Novotny, 2013). This notion links closely to the energy-pollution-water nexus. It can be drawn from earlier sections that MENA would benefit from addressing the dynamics of energy, pollution and water in conjunction.

There is a lack of studies that focus on a holistic and systematic framework to capture the dynamics of energy, water and pollution linkages (Nair et al., 2014). The studies embracing a broad nexus for MENA region are scarce, as highlighted in Section 8.2.

8.2. Energy-pollution-water nexus studies for MENA

MENA has the world's largest reservoirs of energy and has only 1% of the world's renewable water resources (Dubreuil et al., 2013; Damerau et al., 2015). The region is divided into energy abundant states and others that lack access to electricity (El-Katiri, 2014).

Countries that rely on fossil fuels are typically in water-scarce location hence experience water shortages and would benefit more from a nexus. So far, existing nexus studies focus on water demand in fuel production and electricity generation (Siddiqi and Anadon, 2011; Damerau et al., 2015).

Water needed for energy extraction and processing accounts for 2% of the sustainable supply in MENA (Damerau et al., 2015). As conventional oil reservoirs in the region get depleted, extraction technologies shift to more water-intensive technologies (Damerau et al., 2015). Even with improved efficiency, a transition to renewable energy sources and declining energy exports, water consumption for energy will be twice as high as today's values by the end of the century (Damerau et al., 2015). Another study showed that the demand for electricity more than tripled between 2005 and 2050 and demand for water will increase by a factor of 5.6 (Dubreuil et al., 2013). It is recommended that policymakers consider energy implications on water and make water-saving a priority (Siddiqi and Anadon, 2011; Dubreuil et al., 2013). Hence the majority of thermal power plants are turning to seawater (Damerau et al., 2015).

On the other hand, water abstraction, desalination and wastewater treatment constitute the most energy-intensive processes employed in this region (Siddiqi and Anadon, 2011). In Libya, 14% of the total fuel consumption is due to groundwater pumping (Siddiqi and Anadon, 2011). In KSA, up to 9% of annual electricity consumption is attributed to groundwater pumping and desalination (Siddiqi and Anadon, 2011). The other countries in the Gulf region consume 5-12% of total electricity consumption for desalination (Siddiqi and Anadon, 2011). To address the growing issue, renewable energy technologies such as solar water pumping were explored in Egypt and KSA (Dubreuil et al., 2013). A study showed that under a water-saving scenario, 22% of electricity could be saved in 2050 (Dubreuil et al., 2013).

As far as relating pollution to the water-energy nexus in MENA, a study in the GC showed a positive association between energy consumption and CO_2 emissions (Salahuddin and Gow, 2014). Another nexus study was carried in fourteen MENA countries over the period 1990–2011 showing that there is a bidirectional causal relationship between energy consumption and CO_2 emissions (Saidi and Hammami, 2016). Moreover, under a water-saving scenario, 60% of CO_2 emissions can be avoided (Dubreuil et al., 2013).

Cairo is an example of a megacity that struggles to secure resources and control pollution for a growing population (Chirisa and Bandauko, 2015). Egyptian strategies addressing these issues are well conceptualised but disjointed (Chirisa and Bandauko, 2015). Hence Cairo, as a representation of MENA megacities, would benefit from solutions derived from a broader nexus to promote sustainability and resilience (Chirisa and Bandauko, 2015). However, local governments are exposed to resource constraints that pose a challenge to benefit from an urban nexus approach (Chirisa and Bandauko, 2015).

9. Summary conclusion and further work

A number of studies have been carried out on air pollution in the MENA region that focuses on certain countries. This is the first comprehensive review to focus on air pollution in MENA region from a regional and holistic perspective. The region faces the dire consequences of health and climate change emissions translating to economic costs and the loss of its inhabitant's livelihoods. The major sources of emissions are identified and the systems in place to address the issue are assessed. The review then distinguishes the most plausible areas of improvement that need to be focused on to control health and climate change emissions.

Key conclusions drawn from this study are as follows:

- The MENA region is rich with fossil fuel resources; hence, the main source of climate change related emissions is the energy sector. However, emission reduction opportunities within the energy sector are not attractive since energy is needed for growth and development of MENA countries.
- Road transport is the second largest contributor to CO_2 emissions where there is room for emission mitigation and control programs. Finance flows need to shift away from subsidising fuel and energy to establishing public transport infrastructure that will mitigate road transport emissions.
- Most MENA countries have monitoring networks of fixed and mobile stations to collect air quality and emissions data. Nevertheless, the collected data is not employed for effective analysis to support policy makers in setting out reduction plans.
- Most air pollution legislative and regulatory systems in MENA region are based on international environmental standards set by organisations such as the World Bank and the US EPA.
- Emission control programs and technologies are quite inconsistent; however, they have proven successful and effective when adopted and implemented by the private sector. Hence, governments should encourage and facilitate such initiatives by different industrial sectors.
- An urban nexus approach is recommended for the region as an integrated approach to address the air pollution issue in conjunction with other vital aspects such as energy and water.

Some of the key challenges highlighted by this review include the limited work on various pollution sources, their emissions, and exposure for the MENA region. Further field studies are therefore needed to develop a database that could be used for developing emission inventories and health impact assessment studies, besides evaluating the performance of dispersion and emission models. Such development will allow management and control of transport and industrial emissions. This review also highlighted the usefulness of urban nexus approach. This approach could allow a systematic appraisal of energy production/consumption and associated emissions in growing MENA cities for designing appropriate mitigation measures.

Acknowledgements

This work has been carried out under the framework of 'Reducing the Impact of Health and Climate Emissions in Megacity Cairo (RETINA)' project, funded by the University of Surrey and Higher Education Funding Council for England (HEFCE) under the Higher Education Innovation Funding (HEIF). PK also acknowledges the support received from the Qatar National Research Fund (a member of The Qatar Foundation; grant number: NPRP 7-649-2-241).

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